FERMILAB-Proposal-0565

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A STUDY OF THE DETAILED CHARACTERISTICS OF HADRON-NUCLEUS COLLISIONS USING THE FERMILAB HYBRID SPECTROMETER

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May 26, 1977

16 pgs.

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A Study of the Detailed Characteristics of Hadron-Nucleus Collisions Using the Fermilab Hybrid Spectrometer.

Abstract

We propose to study with high precision the incident particle, target and energy dependence of multiparticle production in hadron-nucleus collisions, using metallic foils as the target and the Fermilab Hybrid Spectrometer with the downstream identifier as the detector. We would take data with both a 400 GeV proton beam (or the maximum energy available at the time of the experiment) and a 200 GeV proton plus pion beam incident on targets of Al, Ag and Au. The purpose of this study is to learn more about those aspects of the wave function of fast hadrons which cannot easily be obtained through a study of hadron-hadron interactions, but which manifest themselves in hadron-nucleus collisions. In particular we wish to investigate the A dependence of the average multiplicity and the rapidity distribution. Not only will the hybrid spectrometer measure the true rapidity distribution of the secondary particles, it will also provide particle identification over a wide kinematic range. In addition, it will be possible to detect the decays of associated strange particles. The visual observation of the vertex in the bubble chamber will greatly reduce the systematic errors allowing a one percent determination of the multiplicity. These features are unique to this experiment and will make it possible to discriminate between the many models that have been proposed for multiparticle production with nuclear targets. The experiment requires 400 hours of useful data taking time (10^6 pictures) at 400 GeV and 800 hours (2×10^6 pictures) at 200 GeV, for a total of 1200 hours.

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MOTIVATION

The first generation of experiments at Fermilab on particle production in hadron-nucleus collisions have given many surprising results, and thus attracted considerable interest[1]. The weak dependence on A of the multiplicity in hadron-nucleus collisions [2], the strong dependence on A of particles produced with large P_t[3] and the independence of A of large mass di-muon production[4] have all enforced the idea that the nucleus is a powerful tool for the study of hadronic interactions, in particular of the properties and nature of the state of hadronic matter that exists between the instant of collision of two hadrons and the final production of particles[5].

The interpretation of present data on the multiparticle production in hadron-nucleus collisions is still ambiguous. The data are incompatible with models of particle production in hadron-hadron collisions which have only short range order, or in which the production times of particles are assumed to be short or rapidity independent, but they are still too crude to differentiate between many models which have been recently proposed[6]. For example, it is still not clear if the state of hadronic matter immediately following a hadronic collision can usefully be described in terms of collective variables (as in hydrodynamical models[7] or Gottfried's Energy Flux Cascade model[8]).

Many authors[6] have attempted to interpret the general features of multiparticle production in hadron-nucleus collisions in terms of parton models. The most naive parton model, in which an incident hadron is considered to consist of a single chain of partons, and in which one assumes that only "wee" partons in the projectile interact strongly with the target, is inconsistent with the data. Mueller[9], and Capella and Krzywicki[10], have taken this as evidence that the wave function of fast hadrons is more complicated than one represented by a single chain of partons, while Brodsky, Gunion and Kuhn[11] interpret the data in terms of a mechanism analogous to the Drell-Yan process. Clearly these are fundamental questions which have to be resolved with more precise experiments at the highest available energies. It is for this reason that the above-mentioned authors, amongst others, have emphasized the importance of "second generation" experiments on hadron-nucleus collisions.

There are also purely empirical reasons for a further study of hadron-nucleus collisions from empirical considerations. There are many intriguing observations which need investigation. To name a few: Does KNO scaling really hold for hadron-nucleus multiparticle productions? Is the scaling function identical to that in hadron-proton collisions, as suggested by Ne data[12]? In π^- Ne interactions a large excess of relativistic positive particles has been observed[12]. It has been assumed that these are fast recoil protons from the nucleus. It is important a) to check if the excess is really due to protons (an excess of π^+ would be a fascinating observation!) and b) to study the rapidity distribution and target dependence of these protons. Not only is it difficult to understand the origin of these protons but most theoretical calculations can only predict the production of pions, thus an understanding of the proton contribution is crucial for a meaningful comparison of experiment and theory. Perhaps the target independent central plateau predicted by Mueller for large nuclei already exists at 200 GeV but has been obscured by fast protons! Furthermore, the existence of such protons may be indicative of a possible previously-unrecognized mechanism for the efficient momentum transfer to nucleons in nuclei. Finally, since so far almost all observations on hadron-nucleus collisions have contradicted a priori expectations, it is important to continue the study of these collisions. For example, the study of the A-dependence of strange particles, about which so little is known, is clearly a new area to investigate in this field.

In our minds there is a clear need for an extension to the highest available energies and with the greatest possible precision of the kind of survey carried out by Fermilab Experiment E178[13].

There are presently only two approved "second generation" experiments on the multiparticle production in hadron-nucleus collisions, E451, "Study of the A-dependence of Inclusive Processes and Associated Multiplicity", and E304, "Study of the Interaction of High Energy $\pi^{\pm}$ with Uranium". The former is concentrating on the study of leading particle effects and on processes where at least one particle is produced at large P_t. It is a counter experiment which measures the four vector of the leading particle and the pseudo rapidity of all other charged particles. It can concentrate on events that have a relatively small cross-section. The latter is a bubble chamber experiment in which the authors wish to concentrate their data on one target and one incident particle and energy so as to be able to study, for example, π-γ collisions, direct electron pair rates in a dense medium, and nuclear coherent production.

We are proposing a comprehensive study of the target, energy and incident particle dependence of multiparticle production, which will complement both of the above experiments. Average multiplicity will be measured at the 1% level, a factor 5 better than previously, and for the first time most of the charged secondaries will be identified and have their rapidities, rather than pseudo rapidities, measured.

THE PROPOSED EXPERIMENT

We propose to take data with hydrogen, aluminum, silver and gold targets with a 400 GeV proton beam (or maximum energy available at time of experiment) and a 200 GeV positive secondary beam. The above materials were chosen on the grounds of convenience in handling and equal increments in size. The average nuclear thickness of Al, Ag and Au in units of the absorption length of protons in nuclear matter, are respectively 2, 3 and 3.6.

The rationale for the choice of incident particles and energies is as follows:

The energy dependence of the production process will be studies by taking data with one kind of particle (proton) at two energies; the maximum conveniently available energy and at half that energy. The incident particle dependence will be studied by taking data with both pions and protons at one energy. Approximately 15K events for each energy, target and particle type will be needed. This number will allow a 1% measurement of the average multiplicity, which will be a significant improvement of present knowledge (±5%) and which is needed for comparison with theoretical models. Predictions of most current models differ by $<10\%$. The external particle identifier will be used for identifying π, K and protons above 5 GeV, and ionization inside the bubble chamber will be used to identify protons below 1 GeV.

To minimize systematic errors arising from secondary interactions within the target, thin foils will be used. We estimate that optimum thickness of target is $\sim 1/2\%$ collision length. In table I we summarize the thickness of foils that will be used. All the foils will be inserted simultaneously into the chamber and thus data on all targets, including H_2, will be obtained at the same time. This will minimize A-dependent biases. We also plan to analyze 15K H_2 events at each energy and for each incident particle.

Because of the necessity to use very thin foils as targets, only 10% of the interactions in the spectrometer will occur in the nuclei, the rest will occur in hydrogen. Thus some data for other hydrogen target experiments might be taken at the same time.

EXPERIMENTAL DETAILS

In order for this experiment to be of "definitive" nature, the equipment must have several properties.

a) Excellent 4π coverage. The target fragmentation region is very important.

b) High spacial resolution. The equipment must be able to resolve up to 40 individual tracks.

c) Good momentum measurements up to the highest energy. It is desirable to measure true rapidities, large transverse momenta and particle-particle correlations.

d) Particle identification - mass separation of pions, Kaons and protons from 5 - 100 GeV/c is desirable.

e) Good neutral V particle identification is needed. Almost nothing is known about the A-dependence of strange particle production. This will be the first comprehensive study of this new subject.

The only multiple particle spectrometer that we believe could be designed with all the above characteristics is the Fermilab Hybrid Spectrometer or the European Hybrid Spectrometer (which will not be available for many years). Hence, we propose placing 6 foils, 2 each gold, silver, and aluminum in the vertex detector part of the Hybrid Spectrometer.

One of the objectives of this experiment is a precision ($\sim 1\%$) measurement of the A-dependence of the average charged particle multiplicity. The major precision limitations of these experiments are the systematic errors, not the statistics. We believe that in this experiment we can limit all systematic errors to below one percent and also keep our statistical errors to below this level. Hence, for each energy, incident particle, and target we require 15,000 events. This implies 400 hours of useful data taking time (10^6 pictures) at 400 GeV and 800 hours (2×10^6 pictures) at 200 GeV, or a total of 1200 hours of useful data-taking time (3.0×10^6 pictures). The foil widths and thicknesses are adjusted to give equal number of events in each target materials. See table I.

The major sources of systematic errors are due to secondary interactions and gamma ray conversions in the target material itself, interactions in hydrogen close to the target plates, uncertainties in the hydrogen density and miscounting multiplicities of individual events. We have studied each of these sources of error and believe we can reduce all of them to below the 1% level.

As an example, in order to correct for secondary interactions in the target, there will be two foils for each nucleus as shown in table I. With two thicknesses for each element, corrections can be applied for secondary collisions and gamma ray conversion in the target.

The target will have to be made with great care so as to insure a minimum amount of spurious boiling in the bubble chamber. Since such plates have been successfully installed in other chambers, this should not be a major engineering effort, but some preliminary test will have to be made before the actual data-taking period.

The downstream particle identifier proposed for the Fermilab hybrid spectrometer consists of two parts, a relativistic rise device (Fermilab ISIS) and an atmospheric pressure segmented Cerenkov counter[14]. The first section of the Fermilab ISIS (Fermilab ISIS-1) is under construction and will be tested at Fermilab in September, 1977. It is expected that the complete downstream particle identifier will be installed and tested at Fermilab in May, 1978.

Figure 1 shows the expected distributions of average ionization signals from the complete Fermilab ISIS (Fermilab ISIS-1 and 2) for 10 GeV/c pions, Kaons and protons assuming $N_\pi : N_K : N_p = 10 : 1 : 1$. The three distributions are seen to be quite distinct. Using such curves one can calculate the percentage of the events in a given average ionization region (for example, the Kaon region) that will correspond to particles other than those most probable in that region (for example, pions and protons in the Kaon region). Figure 2 gives these percentages as a function of particle momentum for distinguishing Kaons from pions and protons, and for distinguishing protons from pions. The Fermilab ISIS is seen to be useful for identifying Kaons up to about 40 GeV/c and protons up to about 100 GeV/c. The segmented Cerenkov counter when filled with helium and nitrogen has a pion threshold at ~ 10 GeV/c and a Kaon threshold at ~ 40 GeV/c. It will thus complement the Fermilab ISIS and permit π/K/p identification up to 100 GeV/c.

At the lower energy ~ 200 GeV/c we would like a π^+/p ratio of 1. This has been easily achieved in previous experiments in the N-3 Beam line.

SUMMARY

We request 1200 hours (3.0×10^6 pictures) with the Fermilab hybrid spectrometer to study the particle energy and A-dependence of hadron-nucleus interactions. This experiment is meant to be of "definitive" nature in the survey of multiparticle production in hadron nucleus collisions. It is unique in three ways:

1) Systematics and statistics on average charged particle multiplicities will be kept to ~ 1%. This is a factor five better than previous or proposed experiments.

2) Charged particles will be identified. This is especially important to confirm the existence of the excess of relativistic positive particles seen in neon and to identify their mass.

3) Strange particles will be studied in this type of reaction at high energy for the first time.

Although we do not propose, at this time, a study of $\bar{p}$-nucleus and π^--nucleus reactions, we recognize the possible extreme importance of the role of anti-quarks in this field. We have limited this proposal to protons and pions only because of the technical problems associated with anti-proton beams in the N-3 Beam line. As soon as we determine a way to target high intensity in the N-3 Beam line and stay within the radiation limits (or if these limits change) we will either update this proposal or submit a new proposal requesting an anti-proton exposure.

Library

Addendum to Proposal 565

The purpose of this addendum is fourfold:

i) to bring P565 in line with our understanding of current plans to take in FY79 a total of 2,000,000 pictures in the 30" bubble chamber.

ii) to make the experiment in principle compatible with proposal 570 which has recently been submitted by a part of our collaboration.

Our modified proposal is as follows:

Place the revised set of targets, as listed in table 1, at the upstream end of the bubble chamber and take

5×10^5	pictures with	200 GeV incident	protons
5×10^5	" "	200 GeV π^+ "	"
8×10^5	" "	200 GeV π^- "	"
2×10^5	" "	400 GeV "	"

In Table 1, in addition to listing in detail the properties of the proposed nuclear targets, we list the number of events that will be obtained and the resultant precision in the determination of average multiplicities. The compromises made in the number of photographs and target sizes leads to a reduction in precision of approximately a factor of 2 at 200 GeV and a factor of 4 at 400 GeV. The former is still adequate for all the goals of the original proposal. The latter reduces the scope of the 400 GeV data to that of a survey of hadron-nucleus interactions at the highest available energy. Should this survey reveal new physics which requires further study we would request another exposure.

Taking nuclear data for both polarity beams at 200 GeV expands the scope of P565. Firstly, it allows a comparison of π^+ and π^--induced interactions; secondly, through the use of isospin symmetry and an I=0 target (mg^{24}), it permits a detailed study of the production of relativistic protons in π-nucleus collisions. In view of

Table 1

Properties and Sizes of Targets

Element	Mg	Mg	Ag	Ag	Au	Au
Z	12	12	47	47	79	79
A	24.3	24.3	107.9	107.9	197.0	197.0
Density gms/cm^2	1.74	1.74	10.5	10.5	19.3	19.3
Average thickness of nucleus (in units of mean free path of protons)	1.9	1.9	3.0	3.0	3.6	3.6
Average thickness of nucleus (in units of mean free path of pions)	1.6	1.6	2.4	2.4	2.8	2.8
gms/cm^2	1.94	0.65	1.85	0.62	1.82	0.61
Thickness (mm)	11.1	3.7	1.8	0.6	0.9	0.3
% of collision length for incident protons	2.0	.67	1.2	0.4	1.0	0.33
% of collision length for incident pions	1.5	0.5	1.0	0.33	0.83	0.28
% radiation length	7.8	2.6	20.8	6.9	26.4	8.8
Approximate average charged multiplicity:						
for 200 GeV protons	11.5	11.5	15	15	17.5	17.5
for 400 GeV protons	11	11	13.5	13.5	15	15
for 200 GeV pions	13.5	13.5	18	18	20.5	20.5
Width of foil (cm)	.9	1.0	.9	1.4	1.0	1.8
Approximate % of beam passing through foil	8	16	8	19	19	30
Number of inelastic events per 5 x 10^5 pictures with incident protons	5800	4300	3400	2800	7600	5200
Percent error on multiplicity 5 x 10^5 pictures with incident protons	2		2		2	

One Page Summary

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Table I

Properties and Sizes of Targets

Foil number	1	2	3	4	5	6
Element	Al	Al	Ag	Ag	Au	Au
Z	13	13	47	47	79	79
A	27.0	27.0	107.9	107.9	197.0	197.0
Average thickness of Nucleus (in units of mean free path of protons)	2.0	2.0	3.0	3.0	3.6	3.6
Average thickness of Nucleus (in units of mean free path of pion)	1.7	1.7	2.4	2.4	2.8	2.8
gms/cm^2	.76	1.52	0.58	1.16	.45	.91
Thickness (cm)	0.28	0.56	0.055	0.11	0.025	0.05
idth of foil (cm)	.91	.38	1.83	0.69	2.74	1.07
% of collision length for incident protons	.76	1.52	0.38	0.76	0.25	0.51
% of collision length for incident pions	.56	1.12	0.31	0.62	0.21	0.43
% of radiation length	3.2	6.4	6.5	13.0	7.1	14.1
Average charged multiplicity:						
for 200 GeV protons	11.5	11.5	15	15	17.5	17.5
for 200 GeV pions	11	11	13.5	13.5	15	15
for 400 GeV protons	13.5	13.5	18	18	20.5	20.5
Approximate absorption cross-section (mb) for:						
pions	350	350	950	950	1500	1500
protons	450	450	1150	1150	1750	1750

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(14) "Particle Identifiers for Hadron Physics", V. Kistiakowsky, NALREP, p. 13 (July, 1976).

Figure 1

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10 Gev/c

$N_\pi : N_K : N_p = 10:1:1$